Radio Links for the NASA ABTS

Final Report
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Radio Links for the NASA ABTS:

1

Goals

- Determine Out-Link FSK Bandwidth
- Develop FSK Outlink Transmitter
- Develop Wideband Outlink FSK Receiver
- Develop OOK In-Link Transmitter
- Develop OOK In-Link Receiver
- Marry Out-Link & In-Link Components

- Outlink FSK Bandwidth preliminary inlink transmitter were accomplished in Summer 1995 visit. The calculation of FSK bandwidth is repeated in these notes. Spectrum analyzer measurements of the actual FSK spectrum agree well with the calculations.

- The goal to develop a wideband FSK receiver for outlink data was given first priority for end of Summer 1996 completion.

- The goal of developing OOK inlink transmitter and receiver system components and interfacing all outlink and inlink components into an operating closed loop prototypical system was given a December 1, 1996 completion date.


System Overview

- *FSK* selected for good data reliability and straightforward implementation of biotelemeter and outlink receiver
- *Out-Link Data* is sent *from* the biotelemeter
- *In-Link Data* is sent *to* the biotelemeter
- *Carrier Frequencies:* 174 - 216 MHz.

FSK (Frequency Shift Keying) of the biotelemeter RF transmitter is selected for straightforward implementation of the biotelemeter transmitter circuit and outlink receiver configuration, and good data reliability.

Outlink Data is PCM formatted with header, data, and checksum packets in each data frame. The PCM signal is generated by the biotelemeter microcontroller and FSK modulates the biotelemeter RF carrier. The data rate is about 49.1 kb/s (24.6 kHz) for 8 data channels, when each is sampled at 256 samples/s.

Inlink Data is PCM formatted with header, data, and checksum packets in each data frame. The PCM signal is presently generated by the personal computer connected to the outlink receiver/inlink transmitter serial port. The PCM data On Off Keys (OOK) the 433.94MHz inlink transmitter at 19.2 kb/s (38.4 kHz).

Carrier Frequencies A.R.C. has selected for the biotelemeter outlink signals lie in the biomedical band 174 to 216MHz. See the "ABTS Band Plan" slide.
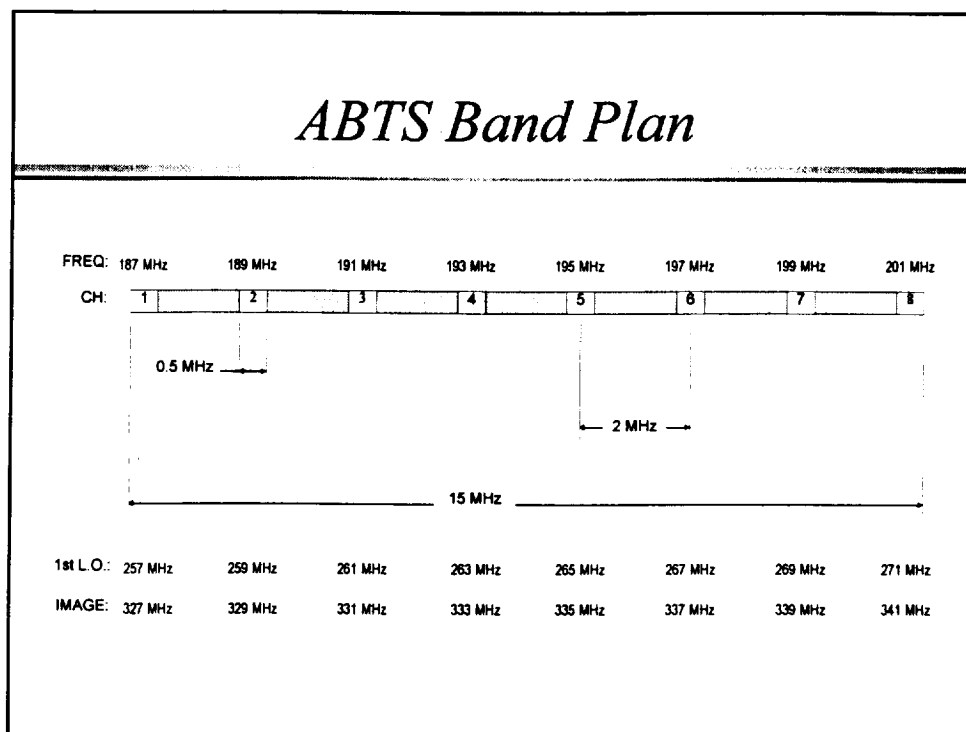
ABTS Band Plan

The **ABTS Band Plan** is arranged according to ABTS requirements ("Final Report, Animal Biotelemetry System Feasibility Study", L. Edsinger and J. Schonfeld, August, 1994).

Note that the example frequencies are within the FCC designated band for wireless biomedical devices and share these frequencies on a non-interfering/accept interference basis with other radio services. The primary users of 174 - 216 MHz frequencies are television broadcasters. Therefore all biotelemetry systems that use this band must choose frequencies accordingly. This may not present any problems in a space setting but it would be prudent to study the occupancy of these frequencies in their target locations. (Including fundamental and harmonic energy that might fall in the band).

In addition to the example fundamental ABTS operating frequencies and "channels", first Local Oscillator and Image frequencies are shown in the slide above for later discussion.

Outlink Bandwidth Calculations

- Packet Rate
- Packet Length
- Baud Rate
- Signal Bandwidth

Packet Rate

Maximum 8 Data Channels + Header and Checksum = 256 Samples/s per channel

Packet Length

1 byte (header) + 16 bytes (data) + 1 byte (checksum) = 18 bytes/packet

8 bits (data) + 2 bits (start & stop) = 10 bits/byte

18 bytes/packet X 10 bits/byte = 180 bits/packet

Baud Rate

180 bits/packet X 256 packets/s = 49.1 kb/s

The apparent data rate then is 24.6 kHz

Signal Bandwidth

$BW = F_{MOD} [2\beta + 1]$ (Carson's Theorem)

Choose Modulation Index = 5 (Allows 5 harmonics)

So signal BW = 24.6 kHz X 11 = 270 kHz

Out-Link Receiver Features

- <u>Frequency coverage</u>: 174 - 216 MHz
- <u>Synthesized</u>: 0.01, 0.1, 1, 2 MHz steps
- <u>Dynamic Range</u>: BDR=67dB; IMD-DR=87dB
- <u>MDS</u>: -115 dBm (SINAD)
- <u>I.F. Bandwidth</u>: 280 kHz
- <u>Outputs</u>: PCM; RSSI; Detector; PLL; Squelch
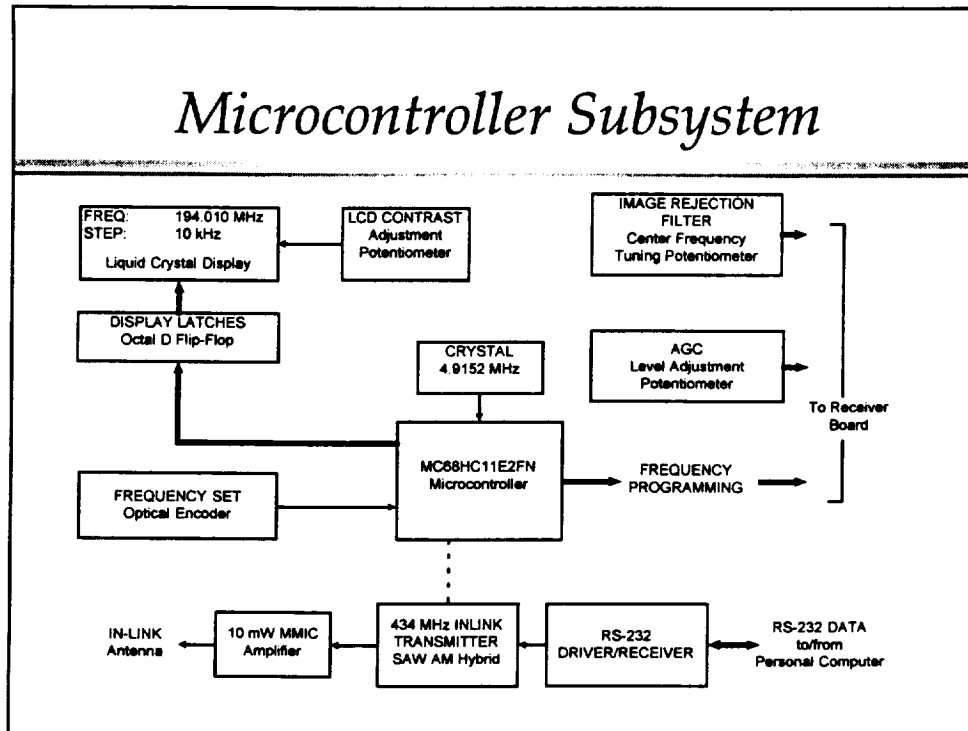- Compatibility with other biotelemetry systems

Receiver Block Diagrams

- ● Receiver RF Subsystem
- ● Microcontroller Subsystem
- ● Frequency Synthesizer
- ● Power Supplies and Audio Output

See following four slides

Receiver RF Subsystem

Broadband Match → GaAs FET Amplifier (AGC) → Image Rejection Filter Voltage Tuned ← Tuning Voltage

Frequency Synthesizer → 244-286 MHz. First L.O. Voltage Controlled Oscillator → Down Converter → MMIC I.F. Amplifier

Frequency Programming from Microcontroller I/O Board → Frequency Synthesizer

80.7 MHz. Second L.O. → Wideband FM IF Subsystem MC13158

Second I.F. Filter FO = 10.7 MHz. BW = 280 kHz

SAW Band Pass Filter F_o = 70 MHz BW = 280 kHz

Outputs → Squelch   RSSI   PCM Data   Detector   PLL Lock

8

Microcontroller Subsystem
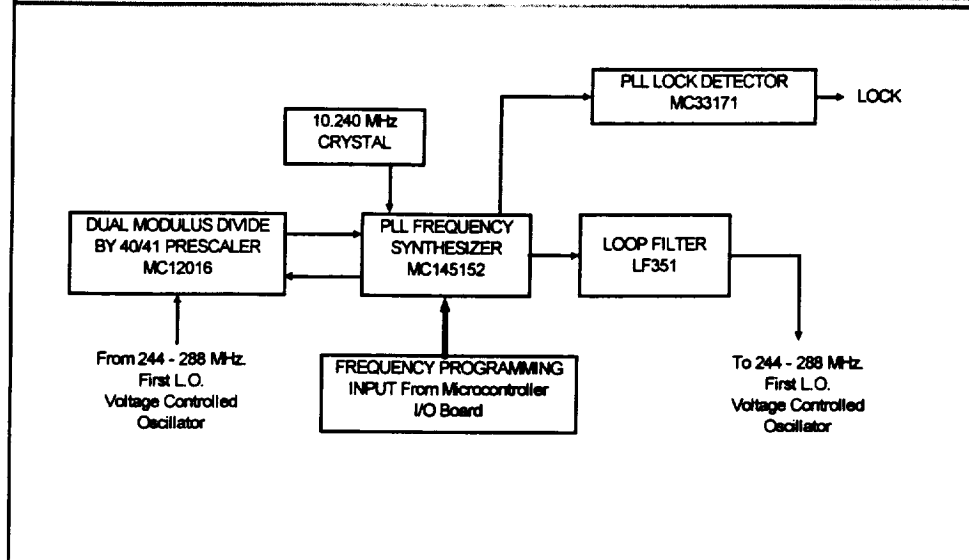

Note that the Image Rejection Filter tuning voltage and the AGC (Automatic Gain Control) voltage can be readily provided by DAC's (Digital to Analog Converter) under microcontroller supervision. In the present receiver implementation these voltages are supplied by potentiometers. The tuning voltage is buffered and available to external preselector filter and preamplifier. This allows tuning the complete system with just one frequency command input.

Frequency Synthesizer

PLL LOCK DETECTOR
MC33171 → LOCK

10.240 MHz
CRYSTAL

DUAL MODULUS DIVIDE
BY 40/41 PRESCALER
MC12016

PLL FREQUENCY
SYNTHESIZER
MC145152

LOOP FILTER
LF351

From 244 - 288 MHz.
First L.O.
Voltage Controlled
Oscillator

FREQUENCY PROGRAMMING
INPUT From Microcontroller
I/O Board

To 244 - 288 MHz.
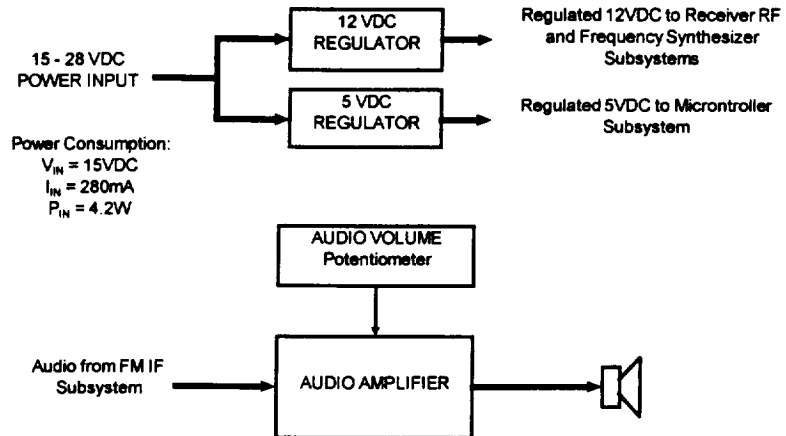First L.O.
Voltage Controlled
Oscillator

The **Frequency Synthesizer** is of conventional design.

• The MC45152 PLL is a CMOS device and the MC12016 is a ECL device.

• The Loop Filter is a 3rd order filter that was designed and modeled using PSPICE.

• An LF351 FET input operational amplifier is the active device in the filter.

• The PLL Lock Detector is a pulse integrator and comparator circuit using a single supply operational amplifier for the active device. A PLL lock indication is provided by a green LED on the receiver's front panel.

• Loop lockup time is about 10 ms for 2 MHz steps

The **frequency programming procedure** for the synthesizer is detailed in the following two slides.

10

Power Supplies and Audio Output

```
                        ┌─────────────┐      Regulated 12VDC to Receiver RF
                        │   12 VDC    │──►      and Frequency Synthesizer
                        │  REGULATOR  │              Subsystems
   15 - 28 VDC      ┌──►└─────────────┘
   POWER INPUT ─────┤
                    └──►┌─────────────┐      Regulated 5VDC to Microntroller
                        │    5 VDC    │──►             Subsystem
   Power Consumption:   │  REGULATOR  │
      V_IN = 15VDC      └─────────────┘
      I_IN = 280mA
      P_IN = 4.2W
```

$V_{IN} = 15VDC$
$I_{IN} = 280mA$
$P_{IN} = 4.2W$

```
                        ┌─────────────┐
                        │AUDIO VOLUME │
                        │Potentiometer│
                        └─────────────┘
                               │
                               ▼
  Audio from FM IF        ┌──────────────┐
    Subsystem    ────────►│AUDIO AMPLIFIER│───────► ◁
                          └──────────────┘
```

Frequency Programming Procedure

- **Uses Motorola MC145152 PLL**
- **F_{RX} = 174 to 216MHz and F_{IF} = 70MHz**
- **F_{LO} = 244 to 286MHz**
- **2-Modulus Prescaler with 40/41 Divide**
- **F_{STEP} = F_{REF} = 10kHz**
- **Clock Divide Value = 1024 so**
  F_{XTAL} = 10.240MHz

- MC145152 PLL has N and A registers
- Registers are loaded in parallel from two latches
- Total divide value = N_T = N x P + A
- N_T = F_{LO} / F_{STEP} = F_{LO} / 10kHz
- Use MC12106 ECL Divider with P = 40

Example: Let F_{RX} = 195.09 so F_{LO} = 265.09MHz

Step 1: Set A = 0:

        N_{TOT} = 265.090 / 0.010 = 26509

        N_{10} = 26509 / P = 26509 / 40 = 662.725

Step 2: Take Integer part of N_{10}: N_{10} = 662

Step 3: Convert N_{10} = 662 to binary:

        N_2 = 1010010110

Step 4: Find A = N_{TOT} - N x P

        A_{10} = 26509 - 662 x 40 = 29

Step 5: Convert A_{10} = 29 to binary:

        A_2 = 011101

Step 7: Program Microcontroller to Generate N and A from Optical Encoder Receiver Frequency Adjust

Synthesizer Design Spreadsheet

- **Design Aid for PLL Programming**
- **Uses High-Side Local Oscillator Injection**
- **For Dual and Single Modulus Prescalers**
- **Enter Receiver Frequency Range, Frequency Step Size, I.F., Prescale Value, Clock Divide Value**
- **Spreadsheet shows N and A Register Programming values in Decimal and Binary**

NASA ABTS RECEIVER - PLL PROGRAMMING
*** HIGH SIDE INJECTION ***

Enter frequency step size, (Fstep) kHz :	10	
Enter Lowest input receive freq, (Frx) MHz:	174	
Enter Highest input receive freq, (Frx) MHz:	216	
Enter Receiver I.F., MHz:	70	
Enter prescale value, (P): (0 = NONE)	40	
Enter TABLE (below) increment, kHz:	2000	

Enter clock divide value (R), MHz:	1024
Dual Modulus: (N and A Counters)	
Freference, kHz =	10.000
Fxtal, MHz =	10.240
Fin max to PLL, kHz will be:	10.000
Single Modulus: (N Counter Only)	
Freference, kHz =	0.250
Fxtal, MHz =	0.256
Fin max to PLL, kHz will be:	7100.00

Manual Calculation: Enter Receive Frequency, MHz. =   196

Receive, MHz.	L.O., MHz	Ntotal base 10	Ntotal base 2	N base 10	N base 2	A base 10	A base 2
196.00	266.000	26600	101111101011010	665	1001100010	0	1010

Receive, MHz.	L.O., MHz	Ntotal base 10	Ntotal base 2	N base 10	N base 2	A base 10	A base 2
174.00	244.000	24400	101111101010000	610	1001100010	0	0
176.00	246.000	24600	101111101010001	615	1001100010	0	1
178.00	248.000	24800	101111101010010	620	1001100010	0	10
180.00	250.000	25000	101111101010011	625	1001100010	0	11
182.00	252.000	25200	101111101010100	630	1001100010	0	100
184.00	254.000	25400	101111101010101	635	1001100010	0	101
186.00	256.000	25600	101111101010110	640	1001100010	0	110
188.00	258.000	25800	101111101010111	645	1001100010	0	111
190.00	260.000	26000	101111101011000	650	1001100010	0	1000
192.00	262.000	26200	101111101011001	655	1001100010	0	1001
194.00	264.000	26400	101111101011010	660	1001100010	0	1010
196.00	266.000	26600	101111101011011	665	1001100010	0	1011
198.00	268.000	26800	101111101011100	670	1001100010	0	1100
200.00	270.000	27000	101111101011101	675	1001100010	0	1101
202.00	272.000	27200	101111101011110	680	1001100010	0	1110
204.00	274.000	27400	101111101011111	685	1001100010	0	1111
206.00	276.000	27600	101111101100000	690	1001100010	0	10000
208.00	278.000	27800	101111101100001	695	1001100010	0	10001
210.00	280.000	28000	101111101100010	700	1001100010	0	10010
212.00	282.000	28200	101111101100011	705	1001100010	0	10011
214.00	284.000	28400	101111101100100	710	1001100010	0	10100
214.00	284.000	28400	110111110110111	710	101100010	0	100111
216.00	286.000	28600	110111110111000	715	101100011	0	0

Receiver Performance Tests

- Blocking Dynamic Range
- Intermodulation Distortion and 3IP
- S+N+D and N+D
- 1st & 2nd Conversion Image Responses
- Mixer Spurs
- 1st & 2nd IF Rejection
- RSSI vs Signal Input Level

Each of these *Receiver Performance Tests* are detailed in the following slides and notes.

Dynamic Range

- Dynamic Range measures the ability of a receiver to function correctly in the presence of strong signals outside its passband.
- For the ABTS outlink receiver, DR is:
  - » Blocking Dynamic Range (BDR) = 67 dB
  - » IMD Dynamic Range (IMD DR) = 87 dB

Blocking Dynamic Range Measurement Procedure:

Receiver tuned to 195 MHz. Signals applied to the receiver from two sources via a combiner at 195 MHz and 193 MHz. Measurements were made with a spectrum analyzer at the first IF SAW filter output. The signal power at 193 MHz was increased until a 1 dB gain compression was noted.

At 195 MHz P_{IN} = -59 dBm. At 193 MHz P_{IN} = -58 dBm caused 1 dB compression.

Noise floor: -125 dBm at 195 MHz brings the signal 3 dB above baseline noise so the noise floor is -125 dBm

Therefore BDR = -58 dBm - (-125 dBm) = 67 dB

IMD Dynamic Range Measurement Procedure:

Apply 195 and 197 MHz signals, equal amplitude, to the receiver. Increase both amplitudes simultaneously until the 3IMD product increases 3 dB above the noise floor.

P_{IN} = -38 dBm resulted in the 3 dB increase in 3IMD

Therefore: IMD DR = -38 dBm - (-125 dBm) = 87 dB

Intermodulation Distortion
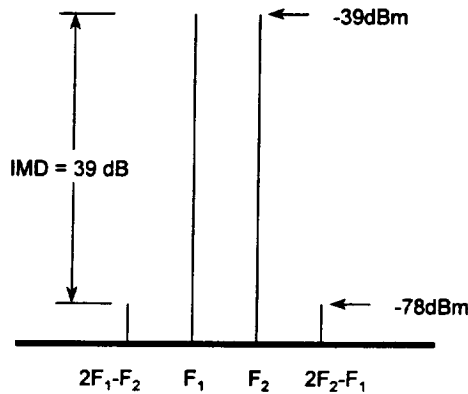
Intermodulation Distortion occurs when a strong signal nearby in frequency to the desired signal combines with the desired signal to generate unwanted products (especially those close-by the desired signal frequency) that can cause interference. It is the non-linear operation of amplifiers, etc. that cause generation of IMD products.

The "close-in" unwanted signals are called the third order distortion products or 3IMD. They occur at $2XF_2 - F_1$ and $2XF_1 - F_2$

The results shown in the slide above were obtained by applying equal amplitude unmodulated carriers (-40dBm) simultaneously to the receiver from two signal sources combined with a 2-way, 0^0 combiner (Mini-Circuits ZSC-1, 4db insertion loss). F1 was 195 MHz and F2 was 197 MHz with 3IMD products at 193 and 199 MHz. Second order responses at 390, 394, 784, and 4 MHz were not significant.

A figure of merit for IMD is the 3rd order intercept point (3 OIP). It was calculated from the 3IMD measurements as follows:

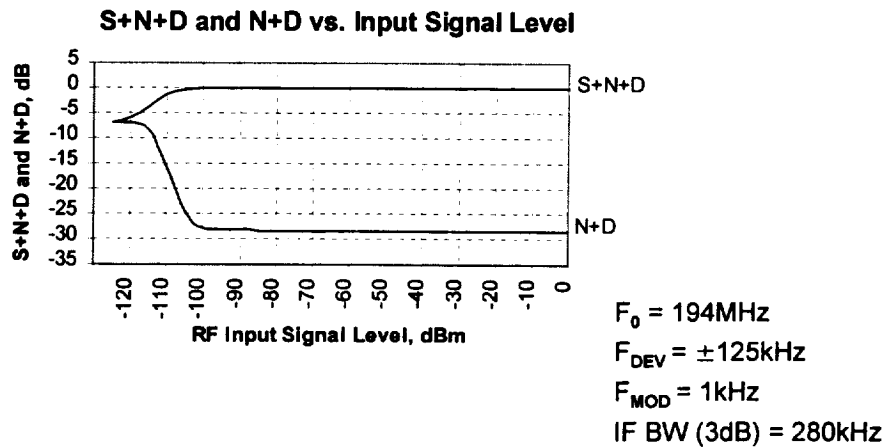$$IP_3 = \frac{n \times P_A - P_{IMn}}{n-1}$$

At 193 MHz:

$$IP_3 = \frac{3 \times P_{F1} - P_{193}}{3 - 1} = \frac{-117 + 75}{2} = -21 \text{ dBm}$$

At 199 MHz:

$$IP_3 = \frac{3 \times P_{F1} - P_{199}}{3 - 1} = \frac{-117 + 78}{2} = -19.5 \text{ dBm}$$

Measurements were made at the first mixer input using a Tektronix 495P Spectrum Analyzer.

$S+N+D$ and $N+D$

S+N+D and N+D vs. Input Signal Level

F_0 = 194MHz

F_{DEV} = ±125kHz

F_{MOD} = 1kHz

IF BW (3dB) = 280kHz

Procedure for S+N+D Measurement:

Apply 194MHz FM signal with 125kHz deviation, 1kHz sine baseband to the receiver. Measure S+N+D voltage (rms) at the detector output as P_{IN} is increased from -127 dBm.

Procedure for N+D Measurement:

Apply 194MHz unmodulated signal to the receiver. Measure S+N+D voltage (rms) at the detector output as P_{IN} is increased from -127 dBm.

Minimum Detectable Signal (MDS):

One measure of MDS is the input power (dBm) where the S+N+D is 3dB (i.e.: twice) the N+D. From the data:

$$MDS = -115 \text{ dBm}$$

S+N+D and N+D detector output voltage measurements were made with a HP-311A Audio Distortion Analyzer.

First Conversion Image Response

Amplitude

|——— 70 MHz ———|——— 70 MHz ———|

Image Filter Response

70 F_{IF} 195 F_0 265 F_{LO} 335 F_{IMG} F, MHz
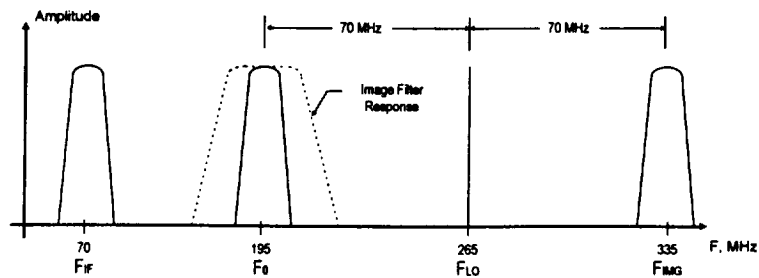
With high-side injection of the first L.O. the *First IF* is:

$$F_{IF1} = | F_0 - F_{LO1} | = | 195 - 265 | = 70 \text{ MHz} \quad (F_{LO1} > F_0)$$

The important *Image Frequency* is:

$$F_{IMG} = F_0 + 2 \times F_{IF1} = 195 + 2 \times 70 = 335 \text{ MHz}$$

Measured Image Rejection Procedure:

Apply F_0 at P_0 then F_{IMG} at P_{IMG} to the Receiver Input

Output Reference : -50 dBm at the 70 MHz SAW I.F. Output

Results:

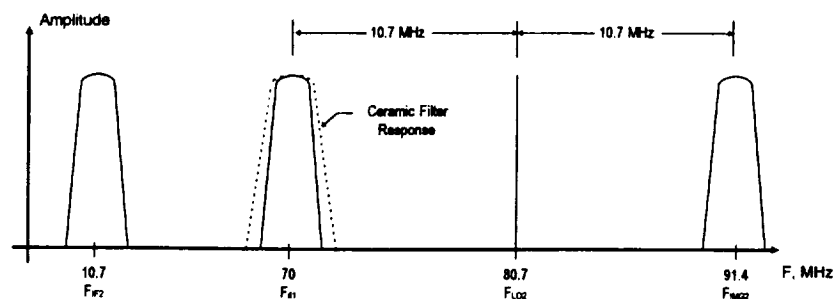At F_0 = 195 MHz P_0 was -105 dBm

At F_{IMG} = 335 MHz P_{IMG} was -32 dBm

Therefore the *Measured Image Rejection* = $P_0 - P_{IMG}$ = -73 dB

See the "ABTS Band Plan" slide for complete Image frequency data

Second Conversion Image Response

With high-side injection of the second L.O. the *Second IF* is:

$$F_{IF2} = |\, F_{IF1} - F_{LO2}\,| = |\, 70 - 80.7\,| = 10.7 \text{ MHz} \quad (F_{LO2} > F_{IF1})$$

The important *Image Frequency* is:

$$F_{IMG} = F_{IF1} + 2 \times F_{IF2} = 70 + 2 \times 10.7 = 91.4 \text{ MHz}$$

Measured Image Rejection Procedure:

Apply F_{IF1} at P_{IF1} then F_{LO2} at P_{LO2} to the Receiver Input

Output Reference: -60 dBm at the 10.7 MHz I.F. Amplifier Output

Results:

At F_{IF1} = 70 MHz	P_{IF1} was -105 dBm
At F_{IF2} = 91.4 MHz	P_{IF2} was -32 dBm

Therefore the *Measured Image Rejection* = $P_{IF1} - P_{IF2}$ = -73 dB

Receiver Spur Analysis

Input Center Frequency (195.00):195.00   BW (42.000):42.000
Output Center Frequency (70.000): 70.000   BW (0.5000):0.5000

Fixed or Variable LO (V): V   Frequency Inversion
LO Center Frequency (265): 265.00   BW (42.000): 42.000

Model   Highest Harmonic: Input (9): 9   LO (9): 9
EXAMPLE: Frequency Steps: Input (21): 21   LO (21): 21
RF=-10dBm
LO=+10dBm   SPURS v1.01 - Kirt Blattenberger 1992

* LO * (-dBc)

	0	1	2	3	4	5	6	7	8	9
0	-	-	-	-	-	-	-	-	-	-
1	-	00	-	-	-	-	-	-	-	-
2	-	69	-	-	-	-	-	-	-	-
3	-	-	50	-	-	-	-	-	-	-
4	-	-	-	66	-	-	-	-	-	-
5	-	-	-	83	69	-	-	-	-	-
6	-	-	-	-	-	74	-	-	-	-
7	-	-	-	-	-	72	77	-	-	-
8	-	-	-	-	-	83	-	83	-	-
9	-	-	-	-	-	-	-	77	-	-

(RF on left axis)

Cases Tested: 193600   Tuesday 16 Jul 1996 10:14:20 AM

Spurious Response analysis identifies the frequencies and approximate levels of spurious signals that might be generated by the first mixer. This analysis aids in the choice of first IF frequency. The table shows acceptable spur levels for a 70 MHz IF for the receiver.

Receiver I.F. Rejection

- **Measured First I.F. Rejection:**

- **Measured Second I.F. Rejection:**

Measured First I.F. Rejection Procedure:

    Apply F_0 at P_0 then F_{IF1} at P_{IF1} to the Receiver Input

    Output Reference: -50 dBm at the 70 MHz SAW I.F. Output

Results:

At F_0 = 195 MHz	P_0 was -105 dBm
At F_{IF1} = 70 MHz	P_{IF1} was -7 dBm

Therefore the ***Measured First I.F. Rejection*** = P_{IF1} - P_{IF2} = -98 dB

Measured Second I.F. Rejection

    Apply F_0 at P_0 then F_{IF2} at P_{IF2} to the Receiver Input

    Output Reference: -60 dBm at the 10.7 MHz I.F. Amplifier Output

Results:

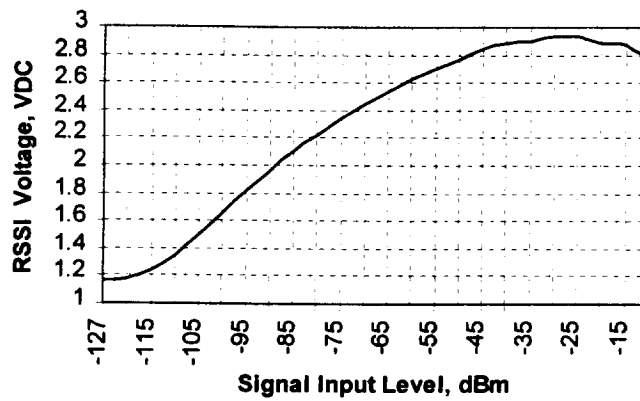|	
At F_0 = 195 MHz	P_0 was -105 dBm
At F_{IF2} = 10.7 MHz	P_{IF2} was > 0 dBm

Therefore the ***Measured Second I.F. Rejection*** = P_0 - P_{IF2} > -105 dB

RSSI

RSSI Output Voltage vs. Signal Input Level

RSSI Dynamic Range:

The approximately linear RSSI range is -120 dBm to -40 dBm
so the RSSI Dynamic Range is 80 dB

RSSI Sensitivity:

The RSSI Sensitivity is the slope of the RSSI Output Voltage vs. Signal
Input Level curve:

Sensitivity = 1.7V / 80dB = 21.25 mV per dB

Receiver I/O Signals for External Use

- ● PC Control
- ● Detector Output
- ● RSSI Output
- ● Conditioned PCM Data
- ● Squelch
- ● PLL Lock Indication

- *PC Control* provides I/O in RS-232 format via a rear apron DB-9 connector. This is presently configured for connection to a personal computer for receiver control and biotelemeter programming and for display of decoded physiologic signals. The enabling software is a WINDOWS application designed by J. Carter.

- *Detector output* provides a voltage proportional to a biotelemeter frequency variation from a programmed frequency. In the event that a biotelemeter slowly drifts after implant this signal can be used to retune the outlink receiver (within an established range).

- *RSSI output* is a voltage that indicates the strength of the received biotelemeter signal. It could be used in conjunction with other received data parameters to suggest animal activity; it is an immediate indication of a signal dropout. It also provides a demodulated **AM output** for potential use with biotelemeters of other manufacture.

- *Conditioned PCM data* is the data presented to the inlink transmitter.

- *Squelch* is a high (carrier strength acceptable) or low (carrier too weak) voltage determined by an adjustable threshold. It is useful for disabling external circuits so that they are not presented with noise.

- *PLL Lock indication* is a voltage (High or Low) that reveals the lock status of the PLL in the frequency synthesizer.

Receiver Usability with Other Biotelemetry Systems

- Frequency Coverage 174 to 216 MHz
- PCM Data Output from FSK:
  - » Buffered Raw data from FM Detector
  - » Personal Computer Formatted (RS-232)
- PCM Data Output from PAM:
  - » Buffered Raw Data from RSSI
  - » Data BW = 3 kHz

The receiver design provides the flexibility for operation with a variety of FSK, FM, and AM biotelemeters using PCM, PIM, PPM, etc. pulse formatted time multiplexed encoding.

24

Team Involved

- Marquette University -
  - » Andrea Biegel - Research Assistant
  - » Aaron Jeutter - Receiver Micro Programmer
  - » Dean Jeutter - RF Circuit Design
- Triomed Electronics -
  - » Jerry Carter - WINDOWS GUI PC Software
  - » Mark Geisler - Software Development for the Biotelemeter Microcontroller

Next Steps

- Summary: A functional Closed Loop prototype demonstrates the feasibility of the ABTS approach.
- Future:
  - » Habitat/Glove box/Centrifuge projects
  - » Biotelemetry System
  - » Needed from ARC Group

Summary:

The closed loop prototype has operational bi-directional wireless links. The Wideband PCM-FSK receiver has been designed and characterized. Now that both links function, communication performance can be addressed. For example, noise problems with the received outlink signal that caused the PC program to lockup were just recently revealed and minimized by software "enhancements" to the Windows based PC program.

A similar problem with inlink communication was uncovered several days before this report: A noise spike or dropout (expected events in the animal Habitat) caused an interrupt to the implant microcontroller which halted outlink transmission. Recovery of outlink transmission did not reliably occur. The problem has been defined and implant software is being modified to better recognize noise from data by changing the timing associated with valid data packet identification and by better utilizing the error flags generated by the microcontroller's SCI circuits.

Excellent inlink performance will also require improvements in the implant's receiver. The biggest performance improvement can be provided by antenna design for the Habitat. The quarter wavelength whip antennas used with the demo prototype inlink leave much to be desired.

Future: See Next Three Slides

Future:
Habitat, Glovebox, Centrifuge

- ● Install system in a Habitat, Glove box, centrifuge project
  - » Parallel activities at both ARC and MU using identical systems
  - » Interface RF subsystems with target enclosures' antennas
- ● Use appropriate enclosure antennas (e.g.: Dr. Philip Carter designs)

• An efficient approach to adapting the ABTS to the Habitat, Glove box, centrifuge project enclosures can be to provide MU with enclosures and antennas and at the same time provide ARC with ABTS components.

• The PCM-FSK receiver was design with a 50 Ohm broadband input. This was done to facilitate easy matching with an external low noise preamplifier and Habitat antenna (Dr. Carter's design). The preamplifier should have a preselector filter matched to the Habitat antenna. The preselector filter can be voltage tuned by the tuning voltage provided at the PCM-FSK receiver output connector. The addition of such a preamplifier can improve overall receiver performance (noise, IMD, dynamic range). Further, with the preamplifier located in close proximity to the Habitat antenna, and with a 50 Ohm coaxial connection to the remotely situated PCM-FSK receiver, overall receiver performance is expected to be excellent.

• The interfacing of the inlink RF with enclosure antenna(s) should be considered soon. The best situation would have one common antenna serving both inlink and outlink. This might require the development of duplexing circuits.

Future: Biotelemetry System

- Biotelemeter
- Outlink Receiver
- Inlink Transmitter
- Inlink Receiver

Biotelemeter

- Prune PCM frame, compress PCM data, and implement new microcontroller (Microchip Corp. PIC Processor) for decreased biotelemeter power consumption

- Finalize implant RF transmitter - minimize power

- Crystal control the implant's transmitter. The CTS-Marden Crystal Manufacturing Co. (Burlington, WI) was contacted recently to discuss the possibility of fabricating a very miniature quartz crystal with fundamental oscillating frequencies available in the 174 - 216 MHz. biotelemetry band. Such a crystal would lend frequency stability (vs. temperature and battery voltage) to the implant's transmitted signal. Reactance modulation would provide the needed FSK.

- Interface with outlink and inlink antennas

- Finalize modular approach to physiologic experiment flexibility

- Begin plans for miniaturization and packaging

Outlink Receiver

- Add DAC's for automatic outlink receiver Image Rejection Filter tuning and for AGC control by receiver microcontroller

- These additions will be made in conjunction with a different microcontroller having more I/O ports including two serial ports (such as Motorola MC68HC12 or Phillips P51XA)

28

Future: Needed from ARC Group

- ABTS interface specifications
- System Decisions:
  - » Antennas
  - » Receivers
  - » Receiver Multiplexing
- Habitat/Glovebox/Centrifuge Test Fixture
- Identify 1 or 2 initial physiology experiments

ABTS interface specifications

- Local and/or PC control? PC-104?
- Volume, cc; Ambient temperature; Vibration, etc.?
- Power available?

System Decisions

- Antennas for Biotelemeter Outlink and Inlink
- Number of outlink receivers per habitat?
- RF Multiplexing required?

Habitat / Glovebox / Centrifuge Test Fixture

- Configuration of Habitat outlink receivers and inlink transmitter
- Separate receiver "boxes"?

Identity One or Two Initial Physiology Experiments

- To set a goal for an initial trial
- Type, number of biomedical signals
- Sequencing time per animal
- Where will all that data go?

Inlink Transmitter

• Improve design for communication in Habitat (increase power?)

Inlink Receiver

• Sensitivity improvements depend largely on design of biotelemeter and Habitat antennas and inlink transmitter power. Communication software improvements in the implant's software will continue.